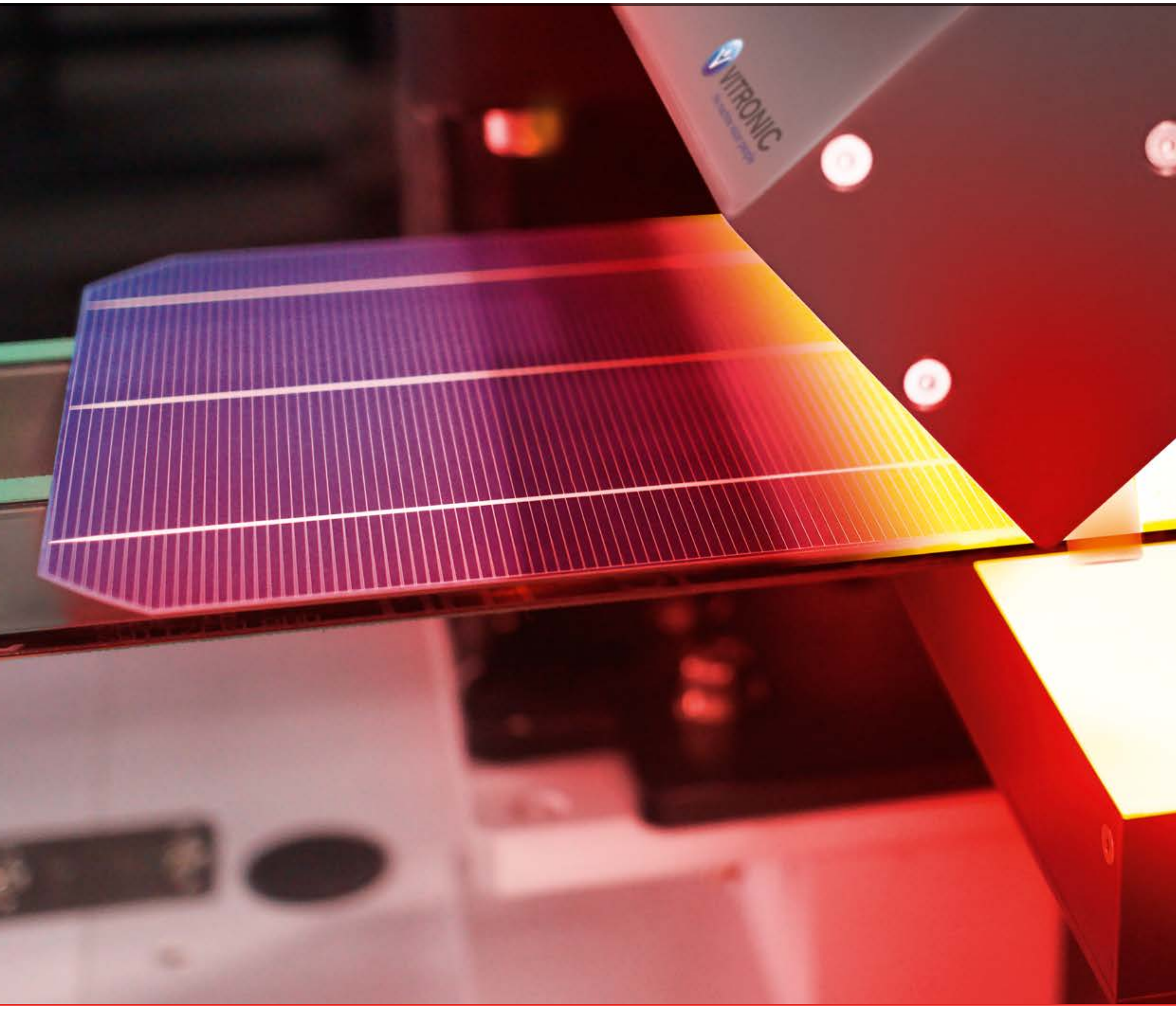
# SOLARUNITED QUALITY INITIATIVE

## WHITE PAPER ON HARMONIZED DATA COLLECTION FROM THE FIELD



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## EXECUTIVE SUMMARY

The solar photovoltaic (PV) market has experienced an accelerated growth accompanied by remarkable cost declines for solar PV technologies. The levelized cost of electricity (LCOE) from solar PV decreased by 73% between 2010 and 2017 – reaching the cost range of fossil fuels. As solar PV power systems become increasingly competitive, constant market growth relies on assurances of performance and durability. In 2017, the International Renewable Energy Agency (IRENA) released the report “Boosting Global PV Markets: The Role of Quality Infrastructure”, displaying Quality Assurance (QA) as an essential instrument for the deployment of renewable energy.

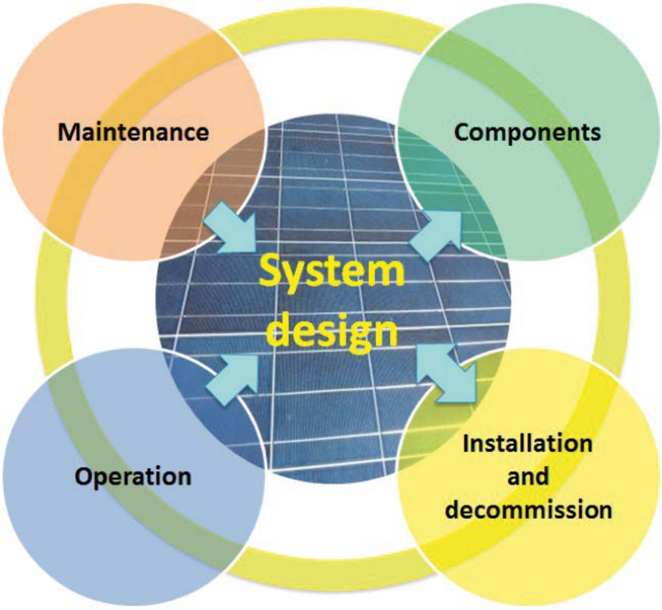
Quality Assurance (QA) guarantees that certain minimum requirements of interoperability, safety, and performance are achieved. At the same time, QA protects and accelerates future PV investments, decreases capital costs, extends module lifespans and lowers the resulting electricity costs. However, comprehensive QA requires physical and institutional infrastructure. **The so-called Quality Infrastructure (QI) comprises the total institutional network and legal framework that formulates and implements standards, testing, certification, metrology, and accreditation.**

Deploying QI plays a key role in the mitigation of technology risk, as well as, the improvement of equipment design, performance, and maintenance. Thus, the adequate establishment of QI should be implemented throughout the technology life cycle to minimize the rate of failures observed for PV projects in their bathtub failure curve. Getting in place the right quality infrastructure can tackle the so-known infant and wear out failures, greatly helping to mitigate risks among different project stakeholders.

*Failure curve of solar photovoltaic systems*

Comprehensive Quality Infrastructure should be thus in place to assure that PV technologies deliver reliable and secure services. A well-established Quality Infrastructure framework that comprises metrology, standards, testing methods, inspections, certifications, accreditation, among others, can mitigate development and operational risks, decrease failure rates and improve the overall performance of solar PV technologies.

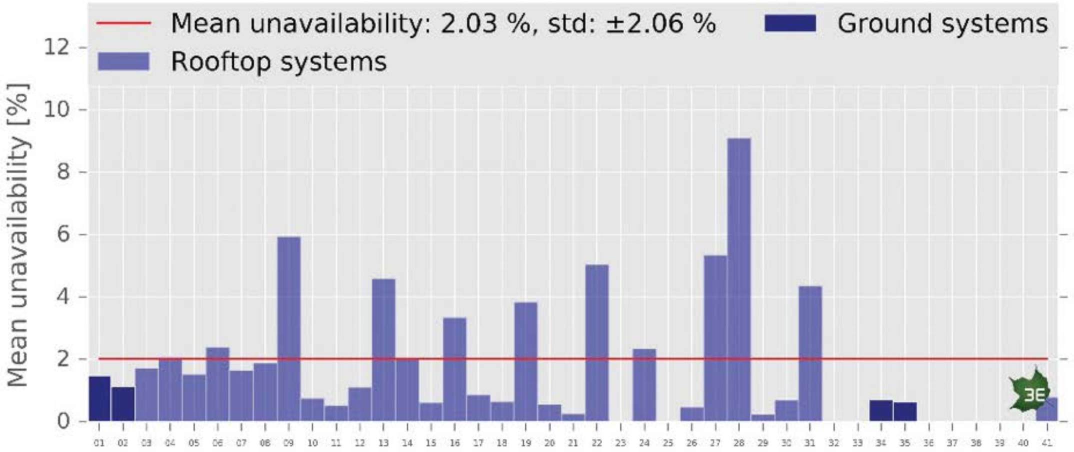
The system design – one of the key factors for quality installations, can be traced back as the root source of failures which becomes evident in the later stage of a PV project. The system should be designed with the constraints of the installation in mind e.g. roof access, ground topography, shading conditions, and presence of soiling sources. A poor design might ignore practical considerations with an impact on the installation phase. Under tight targets, installers may, therefore, alter the design instructions to complete the work faster to the detriment of quality such as walking on panels. The relationship between design and installation is then a two-way relationship and not, as often presented, a dominant cause-effect relation with the design commanding the installation. In fact, common mistakes during the installation phase can easily be avoided through site survey and the monitoring of installations, bearing in mind the design in the choice of components. For example, in areas where soiling is expected, one may choose to mitigate power production with a regular cleaning cycle or to increase the tilt angle to increase the effectiveness in case of rain. The system design should allow cleaning crews to perform their work without walking on PV modules.



*Quality issues often stem from poor design choices (Source: DuPont)*

The maintenance of the PV system in operation should command the design of the installation. or example, inverters that require annual maintenance should for that reason be placed where they can be easily accessible. Equally, as mentioned before, one may need to clean PV modules. Such maintenance procedures cannot be performed on roof installations without dedicated walkways. Finally, a PV system does not just operate itself. The production should be monitored and regular inspections performed. The design will command the monitoring system and should allow offsite monitoring as well as data archiving. The monitoring of the installation should be done according to a reference system.

Mitigation measures - in terms of residual risks in the hands of PV plants owners, are represented by the International Electrotechnical Commission (IEC) certifications and warranties and a well-defined risk transfer matrix. The IEC certification is a design screening test which helps the designer to verify the material and module production process. The certification does assure the lifetime of the PV module and other components, let alone the guarantee of performance. The warranty from the component supplier states an alternative means to mitigate the risk for investors. The typical warranty lasts 10 years for workmanship, covers 10 % power loss within 10 years and 20 % power loss within 25 years. Recently, more and more manufacturers provide linear warranty (e.g. -0.8 % per year) which is more favorable for the investors. **However, caution must be exercised: there is no standardized methodology to calculate the degradation of performance at the system level.** Typically, 5-year data are needed to calculate a degradation rate indicating a certain degree of confidence. In addition, there are many exclusion clauses to prevent a compensation from the manufacturer in case of quality issues. The system owner needs to prove that the problem comes from the inherent defect of the module, which is usually difficult as most problems have various and complicated root causes. It is also difficult for the owner to investigate the technical problems since it requires advanced knowledge about the design of PV modules and systems as well as high-end equipment to measure the defects. Materials suppliers must thus carry some responsibility in the quality of their components. However, in the absence of adequate tests, due diligence (and good faith) cannot be demonstrated. Therefore, until then, one may want to rely on field performance where more data is still needed despite some good attempts.



*Actual unavailability data from most of the PV plants. (Source: 3E)*

The figure above highlights that for some PV plants in a portfolio, the actual unavailability is very high compared to the initial expectations e.g. PV plant number 28. Moreover, the yearly mean unavailability of the analyzed portfolio is around 2 %. A typical assumption of unavailability taken in initial Long Term Yield Assessment (LTYA) studies and O&M contracts is around 1 %. Yet, the unavailability values in the LTYA studies and in the O&M contracts are not necessarily the same as the O&M operators, and they are only liable for plant outages caused by their negligence. Therefore, the unavailability used in the LTYA studies, which in turn will be used to assess the energy production income, is usually higher and should be adapted with the actual availability once representative operational data become available.

Failures and performance losses can be associated with different kind of events, which cannot all be attributed to the technology and its implementation. This paper intends to focus on the events with a technical root cause that could be solved by technical improvements at the planning stage, or at the production stages, or that can be solved with better use of procedures for installation, visual inspections, and maintenance linked to a specific material or components use. It excludes all events related to failures and performances losses which cannot be solved by the upstream part of the PV value chain.

Though, before one starts digging into the different type of failures and the related performance loss, the industry and experts should be involved to move all together towards a **common nomenclature of failures** found in the field. Another critical aspect is related to the metadata of PV plants (location, number of components, and installation date, etc.) which are not collected in a simple and easily accessible format.

Historical data of performance and failure modes of PV systems are not easily accessible to all market players. These stakeholders have a diverse background and can be categorized as investors (private and public), PV plant owners, asset managers, EPCs, O&M operators, and insurance companies. The reasons behind the difficulty to have access to historical data of PV plants relies in the short time upon which most PV systems have been operational so far. Furthermore, a tendency exists among system operators and component manufacturers to keep performance and failure data confidential. This situation should improve because many technical risks assessments and investment decisions regarding the installation of PV plants are based on available information about PV system performance and possible defect rates.

In addition, detailed performance data are in most cases not available for PV plants of the residential and commercial market segment as the cost of monitoring is still perceived as an added cost. Finally, although the description of the failure and corrective measures is common practice in the field of operation and maintenance, this is not often carried out at a sufficient level of detail for PV systems. However, for the PV industry, these performances and failures data are required to have a better understanding of the technical risks, risk management practices, and the related economic impacts. This information is also essential to ensure investors confidence and hence to develop a mature and bankable market.

As a consequence of the different needs between the key actors, O&M operators are in a problematic position to manage all these conflicting requirements over a long period of time.
The best condition for O&M operators is in the presence of a long defect warranty period and low sale price to allow higher OPEX. Recent trends in the PV market have put a lot of pressure on the O&M price which is reported to be as low as 8 Euros/kWp/year in Germany in 2016. A large share of these costs is labor intensive i.e. site keeping and inspection, preventive maintenance,

monitoring, and reporting. It is of utter importance to identify if the O&M scope is mandatory vs optional and the required reaction time depending on the severity of the failure. This can be calculated by assessing the cost of various mitigation options during the operational phase which can be part of an effective O&M strategy.

In the next years, as the availability of measured data will exponentially increase, it will be imperative to build large databases with a potentially harmonized method to increase the confidence level of the statistical analysis and thus reduce the perceived risks for investors. With the available large databases, the minimum requirement can be filtered out to perform tailored and uniform analysis: same granularity, same data, and the same formulas.

Based on the experience described in the paper, the demands from key stakeholders, and the increasing maturity of the sector, we can assume that in the future both upstream and downstream PV quality and reliability will have significantly improved. Also, it is assumed that the future is positioned in the year 2025 and beyond.

In order to achieve this desired future situation for upstream situations, it will be necessary to streamline and further automate PV module production lines. Especially in the last production steps, the cell and the module production, mainly in Asian factories, need improvements. Production capacities of factories are meanwhile counted in Gigawatts, 5 to 10 GW per site are being built already. These can only reliably be produced giving high-quality standards if production parameters are inspected steadily and according to narrow tolerances.

Still, most of the solar cells produced in Mainland China are eye-inspected and hand-sorted or sorted with low-performance Automatic Optical Inspection (AOI). This means that a significant amount of defects is not sorted out and can cause malfunction or degradation later on. State-of-the-art AOI integrated into the Tester/Sorter can ensure the rejection of cells that would probably cause later degradation e.g. bad firing, bad metallization, print interruptions, uneven coating, improper laser openings, missing rear side print and residues from chemicals, etc. Human eye inspection will then be far exceeded.

Inline process control with AOI is even more powerful after most production steps (coating, front, and rear side metallization). Drifts of quality relevant parameters can be observed before relevant defects occur and measures must be taken to always stay within narrow tolerances (short feedback loop).

Big data collected in Manufacturing Execution Systems (MESs) along the production line enables transparent production, quality control, and quality optimization. Up to now, effective MESs are implemented by very few producers. For optimized quality, effective cell tracking is mandatory. It enables to track almost all defects and effects back to their roots by reading the code on the faulty solar cell. Until now, it has only been applied by one major producer.

Consequently, such quality tracking should also be established and used in all module production lines. Some stringer machines are already equipped with effective optical quality inspection. Before or in the final flasher (IV-tester), automatic visible light and electroluminescence inspection can ensure high and equal quality modules for the installation.

This is a call for all investors in PV to push producers to install and maintain a state of the art wafer tracking and inline inspection to prove their effective and continuous usage.

For the downstream situation, including installed PV systems, it can be assumed that:

- It will be possible to make use of the Internet of Things (IoT) to collect information on PV systems and their components and apply Artificial Intelligence / Machine Learning to gather insights;
- Data from PV systems and local distribution grids will be open data, available to various users;
- Most components such as PV modules, inverters, and other power electronics, but also their interfaces with their users, will have smart features;
- Drones will be a common tool that will be applied for visual inspections of PV arrays;
- Simulation models will be even more accurate than nowadays models;
- Allowing reliable forecasting of the performance of PV systems on short and long time scales.

This improved technical context will create better access to diverse types of data to PV system experts - but also the owners of PV plants - leading to a better understanding of key factors influencing real-life relations between performance, reliability, and durability.

For reliability and durability research, performance data will be used first to determine the rate of degradation of PV module and systems. Secondly, failure modes will be collected, identified and statistically evaluated. This evaluation will happen in the context of, among others, location, hence irradiation, the lifetime of the PV modules/systems, typical components and modes of installation, system operation and integration with the grid as well as maintenance schemes. Assuming higher statistics of data collection of large amounts of PV systems in the future, it will also be possible to process these data and related indicators by statistical methods originating from the field of maintenance research, such as FMEA[1], cost-based FMEA, CPN methodology, and Multi-variables Analysis.

As PV systems in the future will become more complex - due to the integration of energy storage and grid stabilization functions – it is of utmost importance that besides the existing quality control for the system components, independent quality assurance for system design and engineering is established. This quality assurance needs to focus on the key aspects of system performance, reliability and safety.

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[1] FMEA: Failure Modes and Effect Analysis

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